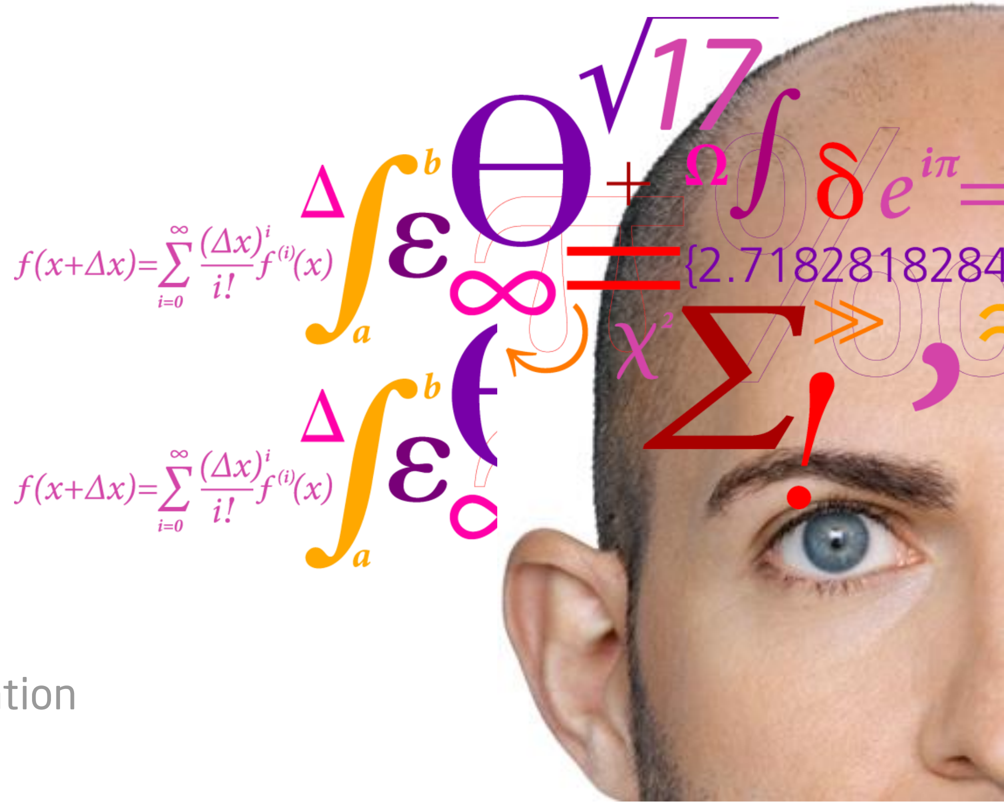
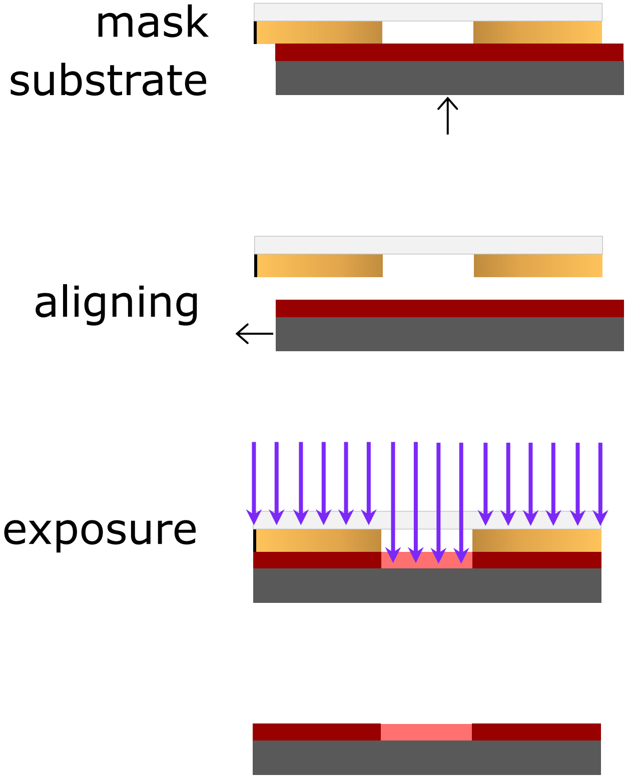
Lithography Tool Package

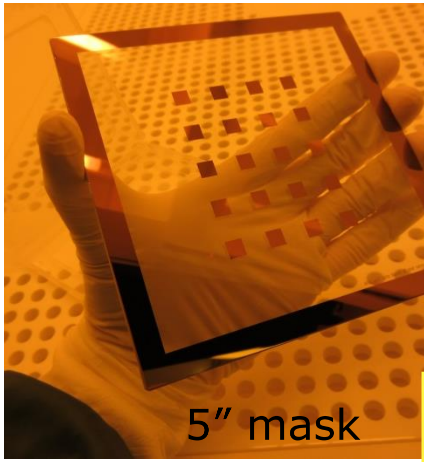
Exposure

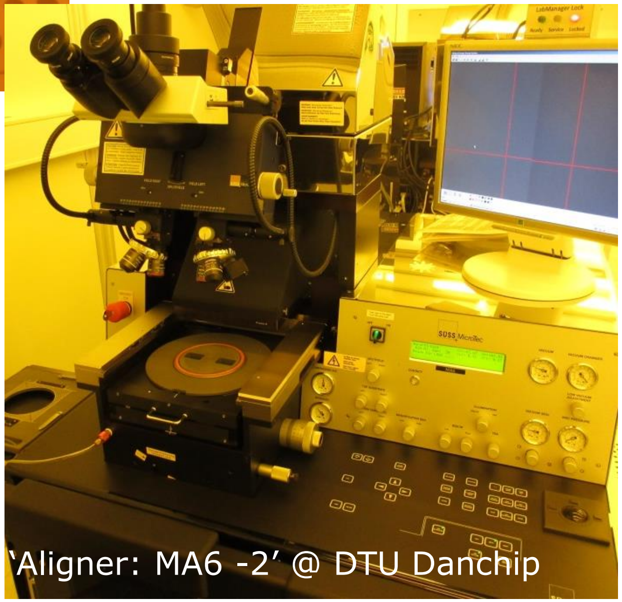


DTU Danchip
National Center for Micro- and Nanofabrication

Mask aligning and UV exposure




5” mask

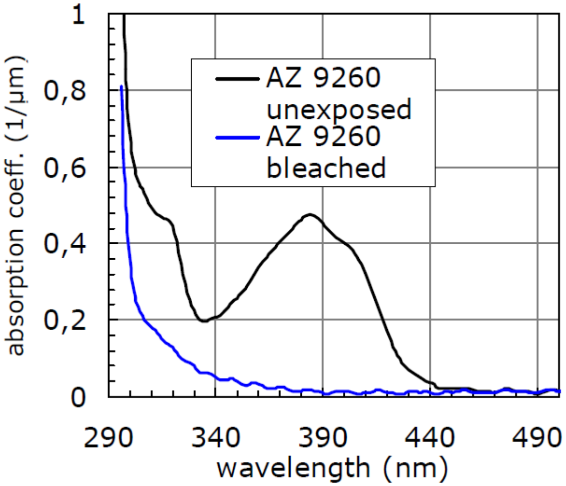

‘Aligner: MA6 -2’ @ DTU Danchip

Photoresist: composition

- **Resin**: Monomers or polymer chains of varying length (solid at RT)
- **Photo-active component** (PAC): Reacts with UV-light during exposure and changes the resin
- **Solvent** (~70%): Dissolves the resin in order to enable coating

- After spin coating and softbake, most of the solvent has evaporated, leaving only resin and PAC in the film on the substrate

- Optical properties
  - Absorbs UV-light (spectral sensitivity)
  - Absorption decreases during exposure = *bleaching*



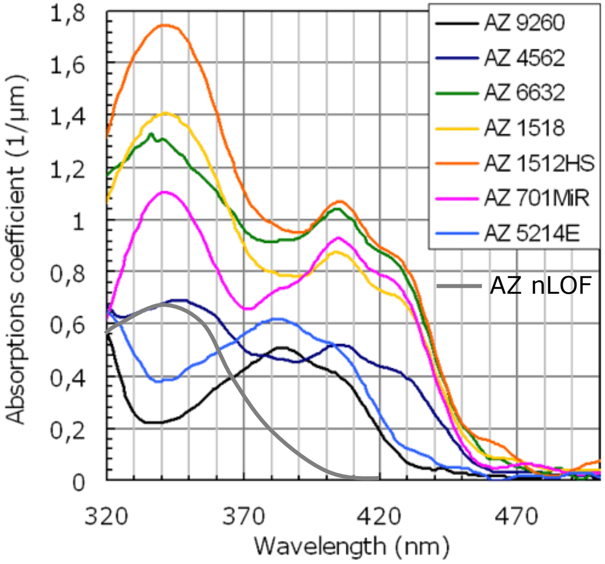
From http://www.microchemicals.eu/

Photoresists at DTU Danchip

- Most UV-resists at DTU Danchip are
  - Manufactured by AZ-Electronic Materials (formerly Hoechst/Clariant)
  - Distributed by MicroChemicals GmbH
- SU-8 is manufactured by MicroChem Corp and distributed by Micro Resist Technology GmbH

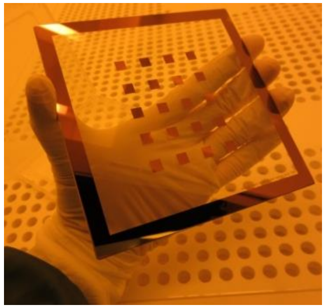
- nLOF doesn’t bleach
- 5214E can be reversed
- Spectral sensitivity -------------------------→

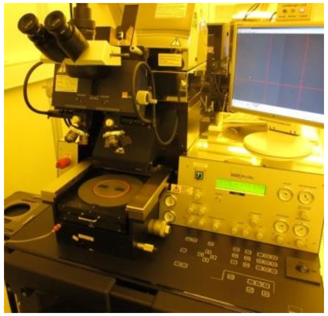
From http://www.microchemicals.eu/



	MiR 701	nLOF 2020	5214E	4562	SU-8
Thickness	1.5–4 µm	1.5–4 µm	1.5–4 µm	5–10 µm	4–200 µm
Positive	x		x	x	
Negative		x	x		x

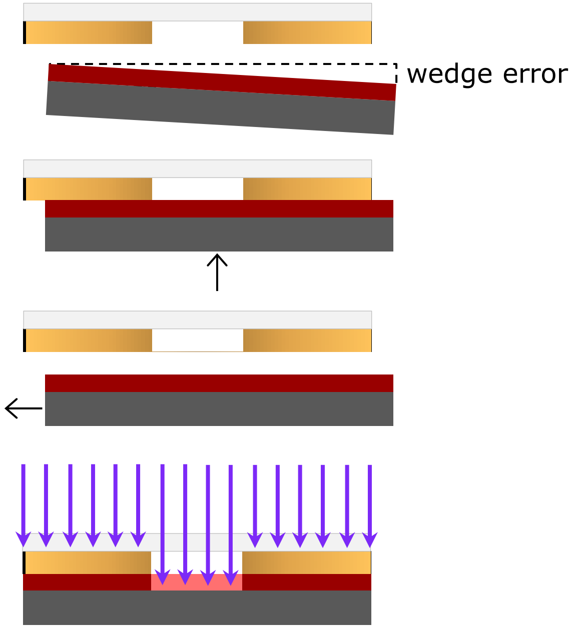
Exposure: procedure and hardware





Mask

- A glass plate with chrome pattern
- Commercially produced, usually laser or e-beam lithography
- Anti-reflection coating makes chrome side brown



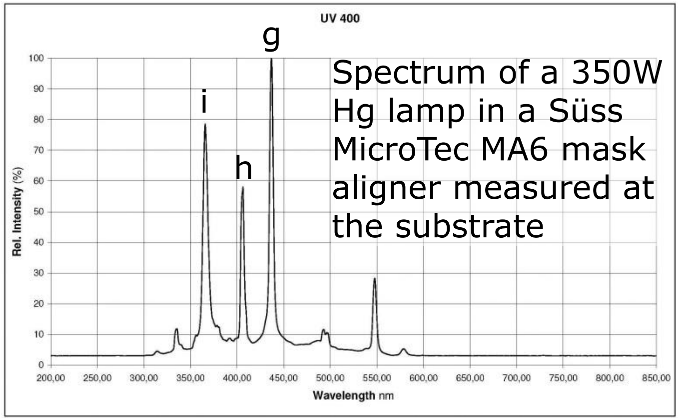
Exposure procedure

- Load substrate into machine
- Machine performs **W**edge **E**rror **C**ompensation: substrate surface is made parallel to mask
- Align substrate to mask: the substrate is moved in order to align marks on the substrate to marks on the mask
- Expose substrate: the shutter is opened for a predefined time

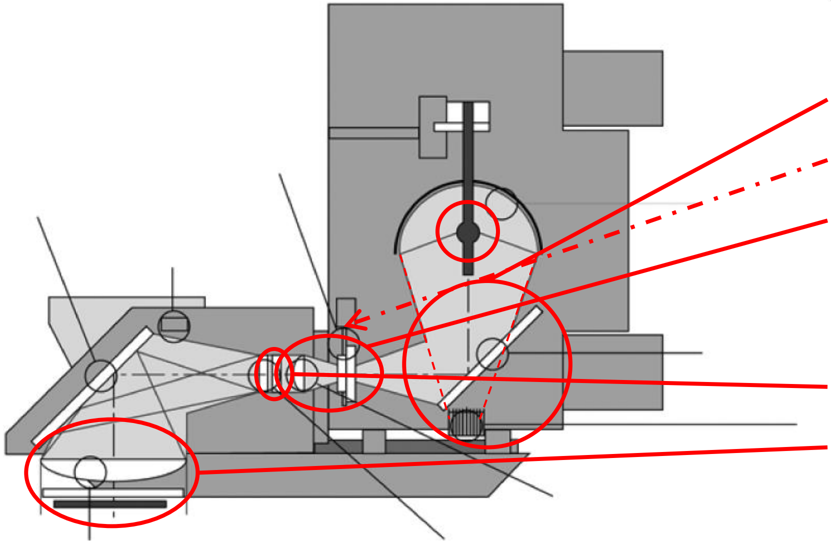
Exposure: procedure and hardware, cont.

Exposure source

- Mercury arc lamp: emits spectral lines on top of thermal light
- High power input, most is lost (heat, unwanted wavelengths)
- Most used spectral lines: 365nm (i-line), 405nm (h), 436nm (g)



Spectrum of a 350W Hg lamp in a Süss MicroTec MA6 mask aligner measured at the substrate



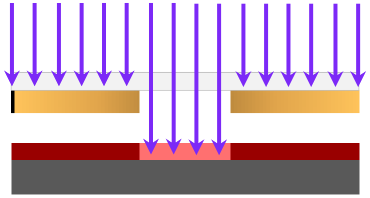
Exposure optics

- Cold mirror: dumps white light
- Shutter: blocks the light
- Fly’s eye lens (lens array) and condenser lens: makes the light spatially uniform
- Filter: selects the desired line(s)
- Front lens: collimates the light (parallel beams)

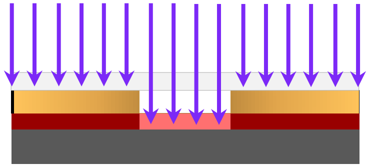
From Sami Franssila, *”Introduction to Microfabrication”* 2010

Exposure: process parameters

Exposure mode



- Proximity: mask and substrate are separated by a gap of e.g. 10µm during exposure
  - Pros: the mask does not get dirty → hundreds of prints
  - Cons: reduced resolution (line broadening, corner effects)
- Contact: mask and substrate are in close contact during exposure
  - Pros: highest resolution
  - Cons: the mask gets dirty → a few prints
  - Subtypes: soft, hard, vacuum

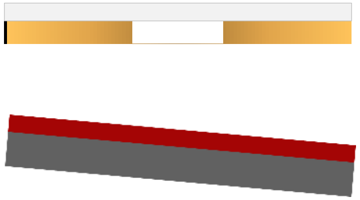


Exposure dose

- Dose = intensity * time [mW/cm^2 * s = mJ/cm^2]
- Optimal dose is a function of many variables
  - Resist; sensitivity, thickness, softbake parameters
  - Exposure light; wavelength, intensity
  - Developer; chemistry, temperature, time
  - Mask material: absorption (quartz or other glass)

Exposure: details

Wedge Error Compensation



- The stage pushes the substrate on the chuck against the mask while being able to tilt (roll and pitch)
- Once contact has been established, the tilt is locked, enabling the stage to move down while maintaining parallelism

Contact printing

- *Soft contact*: many good prints
  - Same force as WEC
- *Hard contact*: ~10 very good, uniform prints
  - The vacuum between substrate and chuck is replaced by a N_2 pressure, forcing substrate and mask in closer contact
- *Vacuum contact*: 1 perfect print, thereafter only perfect in areas
  - A chamber is created between chuck and mask (by inflating a rubber ring around the substrate), and the space between substrate and mask is evacuated

Exposure: resolution

Theoretical resolution limit

$$R = k\sqrt{\lambda\left(s + \frac{z}{2}\right)}$$

s: gap between mask and resist

z: resist thickness

λ: wavelength of exposure light

k: a constant, theoretically 1.5

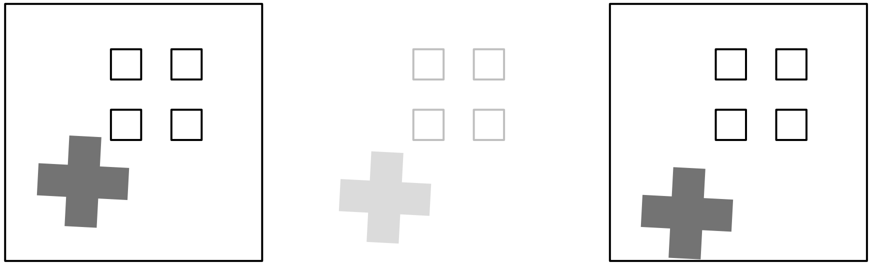
Adapted from Marc J. Madou "*Manufacturing Techniques for Microfabrication and Nanotechnology*" 2011. Valid for a (two dimensional) grating with period 2R.

Practical resolution

- In practice, resolution is decreased by resist contrast, stability (aspect ratio), and adhesion to substrate, as well as the contact during printing (both across the substrate and from print to print)
- k > 1.5 → k ≈ 2.5
- Critical dimension (minimum feature size) should always be CD > R
- 3µm is possible everyday; 1.25µm only when you are lucky

Exposure: alignment

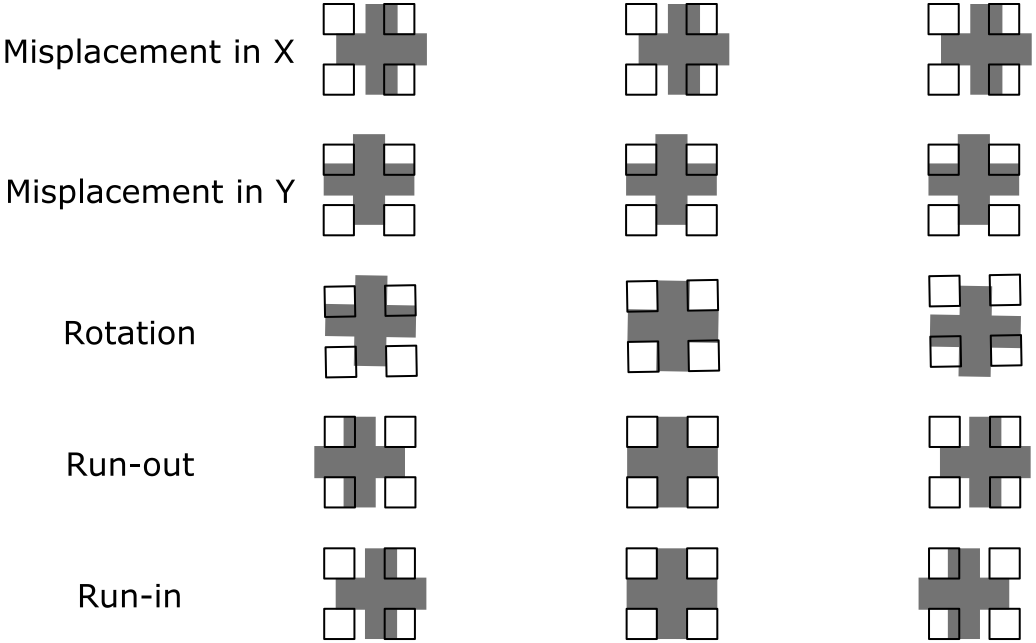
- Using stage translation and rotation, the substrate is aligned to the mask



Alignment accuracy

- Manual alignment to ±1μm is possible, but expect up to ±3μm
- Remember to include tolerance in your design!

Misalignment



Depends on:

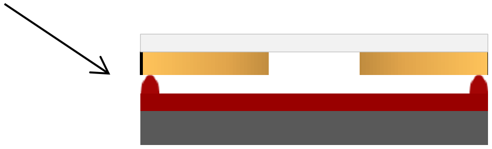
- Alignment mark design
- Operator experience
- Previous processing of substrate
- Equipment condition

Exposure: exercise

- What is the effect of a 2µm edge bead on the resolution limit of i-line exposure (365nm) of a 2µm resist film in the case of contact printing, and proximity printing (proximity gap = 10µm), respectively?

- Contact printing:
- R = 0.91µm without edge bead (s=0µm)
- R = 1.57µm with 2µm edge bead (s=2µm); almost 75% increase

- Proximity printing:
- R = 3.01µm without edge bead (s=10µm)
- R = 3.27µm with 2µm edge bead (s=12µm); less than 10% increase
- Why does the gap still increase in proximity mode?



WEC determines "0"

$$R = k\sqrt{\lambda\left(s+\frac{z}{2}\right)}$$

s: gap between mask and resist

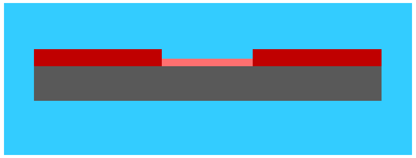
z: resist thickness

λ: wavelength of exposure light

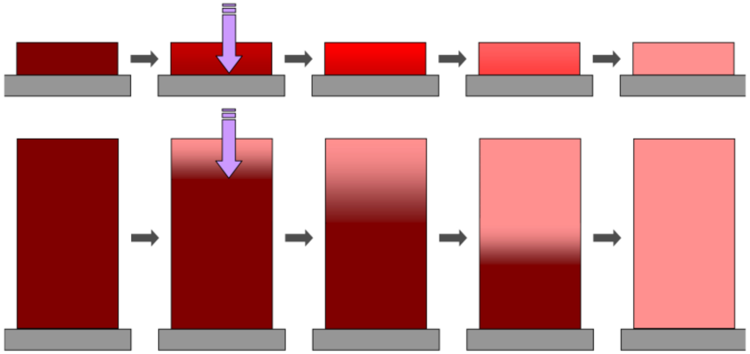
k: a constant, theoretically 1.5

Photoresist: tone

Positive tone

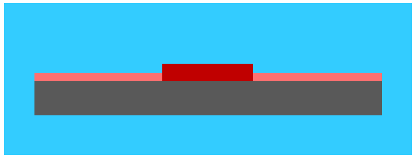


- Exposed resist becomes soluble in developer
- Polarity change or chain scission
- Bleaching during exposure enables straight sidewalls even for thick resist
  - the dose is a function of the resist thickness



From http://www.microchemicals.eu/

Negative tone

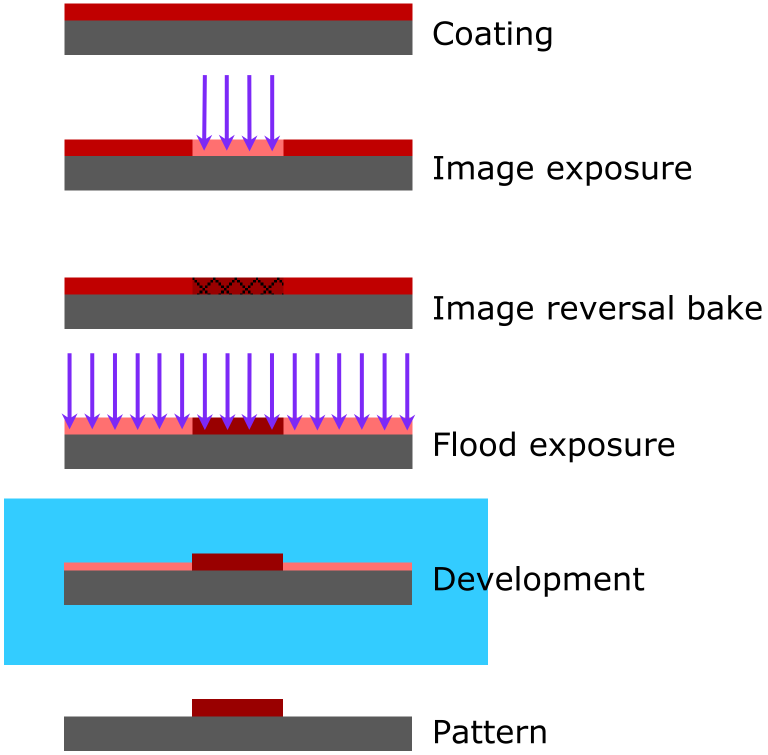


- Exposed resist becomes insoluble in developer
- Polarity change or cross-linking (usually requires PEB)
- Special case: no bleaching (AZ nLOF 2020) → always negative sidewalls
  - the dose is approximately constant

Photoresist: special categories

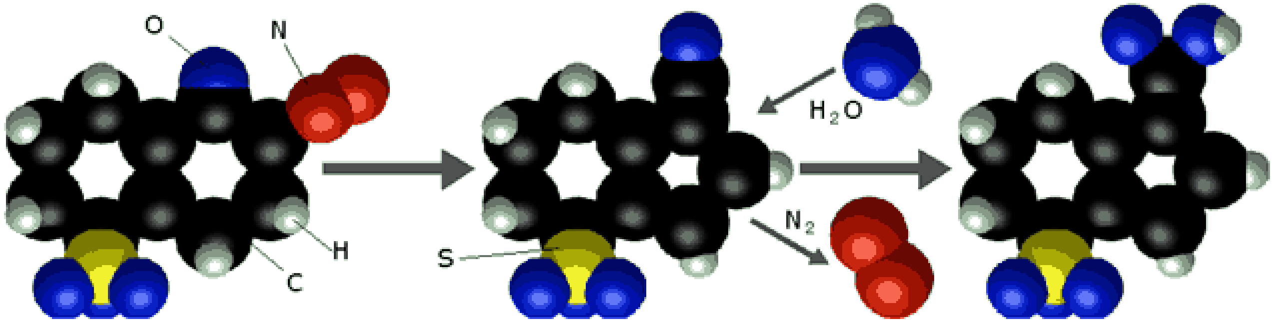
- Image reversal resist (AZ 5214E)
  - Positive resist changed to negative by additional process steps
  - Cross-linker (NH_3) is added, activated by the *image reversal bake*
  - The temperature of the image reversal bake is a critical parameter
  - Requires flood exposure before development

- Chemically amplified resists
  - Photo-initiation is catalytic
  - Requires PEB
  - Dose = light + heat
    → higher throughput



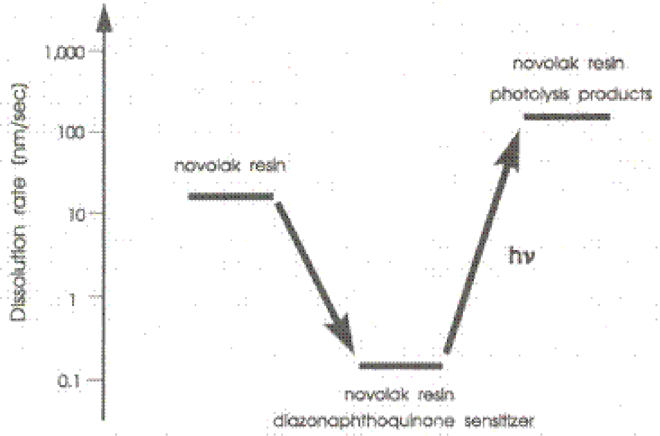
Photoresist: photo-chemistry

- AZ 5214E and AZ MiR 701 have **d**iazo**n**aphtho-**q**uinone-sulphonate (DNQ) as the photo-active component, or photo-initiator
- During exposure, DNQ absorbs the exposure light, and transforms into a corboxylic acid while releasing N_2 and absorbing H_2O
- UV +



From http://www.microchemicals.eu/

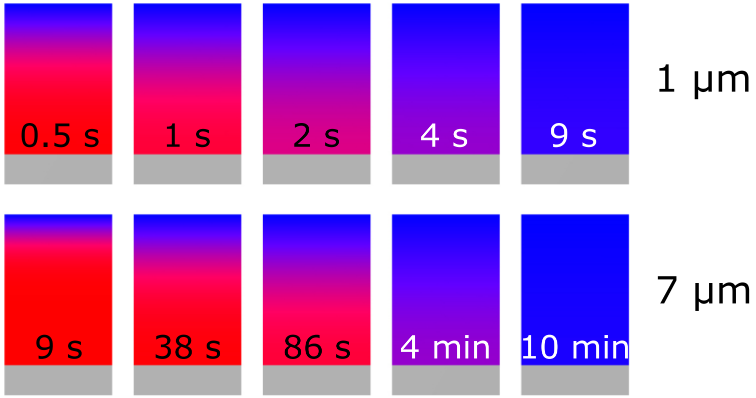
- DNQ lowers the solubility of the resin in the developer, while the corboxylic acid increases the solubility
  - → positive tone resist



From http://www.micronanofab.eu/

Photoresist: photo-chemistry, consequences

- After softbake, the resist has to rehydrate in order to enable exposure
  - 1µm rehydrates in 10s
  - 10µm requires at least 10 minutes
  - Thicker films may require hours to rehydrate
  - Insufficient rehydration leads to under-development and/or non-straight sidewalls



From http://www.microchemicals.eu/

- After exposure, the N_2 has to outgas before any thermal process in order to prevent bubbles from forming
  - Before image reversal bake (5214E), and possibly PEB (MiR 701)
  - 1µm outgasses in ~1 minute, 3µm in ~10 minutes, while a 10µm film may require hours to outgas
  - Thick resist should be exposed in intervals with delays in between

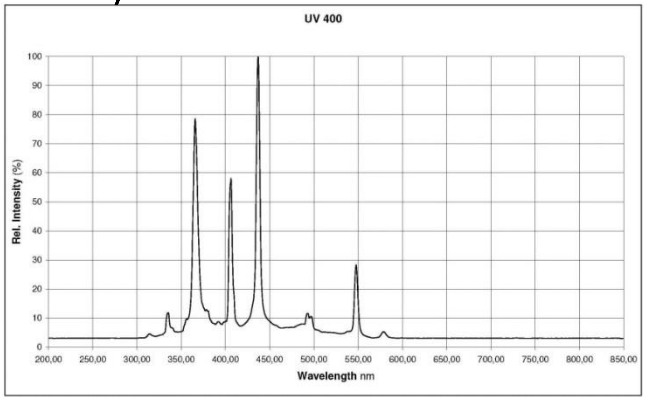
- AZ nLOF 2020 and SU-8 both have a different PAC, and do not require rehydration or outgassing

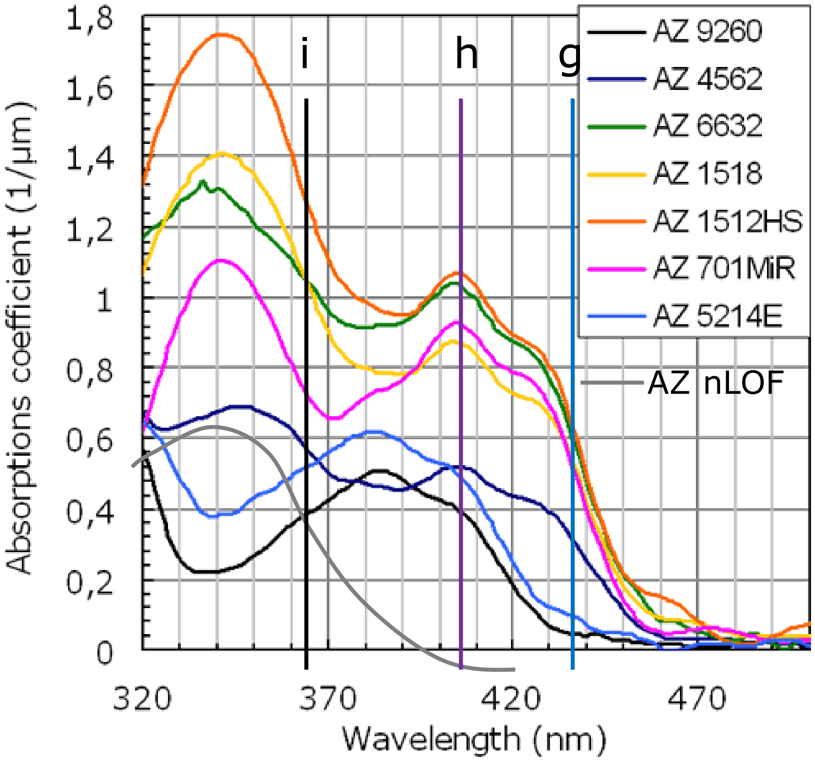
Photoresist: exercise

At DTU Danchip, some aligners expose using only the i-line, while others use broadband (i+h+g) exposure.

Estimate the change in exposure dose when changing from i-line exposure (365nm) to broadband exposure (365nm + 405nm + 436nm) for

- MiR 701
  - ~1/3 dose
- nLOF 2020
  - No change
- 5214E
  - ~1/2 dose





From http://www.microchemicals.eu/

Outline

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- Process effects
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